5.9.5 LOSS OF PRESTRESS

Elastic Losses or Gains, Δf_{pES}

Δf_{pES} is the sum of all the losses or gains to the strand stress due to elastic shortening or extension caused by either internal (prestressing) or external (gravity) loads applied to the concrete section.

Δf_{pES} should be calculated using either the iteration of Equation 5.9.5.2.3a-1 or directly solving with Equation C5.9.5.2.3a-1.

Long–Term Losses, Δf_{pLT}

Δf_{pLT} is the sum of losses due to long-term shrinkage and creep of the concrete, and relaxation of the prestressing steel.

There are 2 methods listed in the AASHTO LRFD code for computation of long-term losses:

1. The approximate estimate according to the provisions of Article 5.9.5.3 and Equation 5.9.5.3-1.

2. The refined estimates according to the provisions of Article 5.9.5.4.

Method 1 is an approximate method that gives reasonably good results (as compared to Method 2) for conventional prestressed girders with a composite cast-in-place deck; however this method can be unconservative for girders without a cast-in-place deck.

Method 2, the refined method, presumably results in the most accurate estimate of long-term losses for all prestressed girder types with or without a cast-in-place deck, however it requires significantly more effort than Method 1. For typical bridge construction with a conventional prestressed girder and a cast-in-place deck, Method 2 will not yield significantly different or better results as compared to Method 1. It is the Bridge Section's opinion that for conventional prestressed girders with cast-in-place deck the presumed level of accuracy achieved by using Method 2 is seldom warranted or even possible because the material properties that effect creep and shrinkage and the times for various load application are either unknown or beyond the control of the bridge designer.

In general, Method 1 may be used for typical ITD bridge construction that involves precast, pretensioned members with a composite cast-in-place slab. Method 2 may be used for all prestressed girder types but must be used for precast, pretensioned members without a composite slab (such as deck bulb tees, side-by-side voided slab sections, etc) the use of Method 1 in this case would be unconservative.

The term "construction staging" as used in C5.9.5.3 is understood to refer to a member that is constructed in stages rather than a bridge that is constructed in stages. Examples of members that are constructed in stages are segmental construction and post-tensioned spliced precast girders.

Design Assumptions for Method 2 (refined estimate of losses)

It is ITD policy to use 55% humidity for all locations in Idaho.

When using the refined estimate of losses (Method 2) there are some assumptions that need to be made concerning the age of the girder concrete (ageing starts at the end of the cure period) at transfer, at deck placement and at final time. Also the age of the deck concrete is also required for the determination of losses or gains due to loads applied to the composite section (such as rail loads and wearing surfaces). Because these ages are not usually known during the design process some conservative assumptions should be made.

The sooner a cast-in-place deck can be placed on prestressed girders the lower the long term prestress loss will be. Consequently the design should be based on the deck being placed at the latest practical time; this will result in the greatest long term losses and thereby produce a more conservative design. Therefore, if no better information is known, it is ITD policy to assume the following:

For Prestressed Girders with Composite cast-in-place Decks,

Age of girder at transfer = 0.75 days   (a smaller number will result in greater prestress loss)
Age of girder at deck placement = 270 days   (a larger number will result in greater prestress loss)
Age of deck at composite loading = 1 day   (a smaller number will result in greater prestress loss)
Final time = 3650 days   (a smaller number will result in less prestress loss, a larger number has little effect)

For Prestressed Girders without cast-in-place Decks,

Age of girder at transfer = 0.75 days   (a smaller number will result in greater prestress loss)
Age of girder at installation = 15 days   (a smaller number will result in greater prestress loss)
Final time = 3650 days   (a smaller number will result in less prestress loss, a larger number has little effect)

The assumed values above were chosen to be conservative in most cases. If the designer has information to more accurately predict the number of days for the various conditions listed above different design values may be used in consultation with the Group Leaders.

Commentary:

The total loss of prestress, Δf_{pT}, is defined as the difference in the stress in prestressing strands immediately before transfer (the jacking stress) and the effective stress in the prestressing strands after all losses, f_{pe}. The total loss of prestress, Δf_{pT}, is further defined as the sum of elastic losses and long-term (also called time-dependent) losses. For typical pretensioned, precast members with low-relaxation strand, the above definitions can be re-stated as the following equations:

$$f_{pe} = (0.75 * 270 \text{ ksi}) - \Delta f_{pT} \qquad \text{Where } 0.75 * 270 \text{ ksi is the jacking stress.}$$

$$\Delta f_{pT} = \Delta f_{pES} + \Delta f_{pLT} \quad \text{(Eqn. 5.9.5.1-1)} \qquad \text{Where } \Delta f_{pES} \text{ is the elastic loss and } \Delta f_{pLT} \text{ is the long-term loss.}$$

Δf_{pES}, elastic losses or gains, occur instantaneously at the time of load application. While Δf_{pES} consists of many different components, one for each load, there are two general categories. The first category is the elastic loss that occurs immediately after transfer of the prestress force to the girder (loss due to prestress combined with gain due to the member self weight). The second category is the loss or gain due to additional loads, such as non-composite dead loads, composite dead loads and live loads that are applied after transfer. It is ITD's policy to ignore the effects of this second category for simplicity and the fact that it is conservative to due so because in most cases this effect would result in a gain or increase in prestressing force.

Δf_{pLT}, long term losses, occur due to long-term shrinkage and creep of concrete, and relaxation of the prestressing steel.

Sign Convention

When loads or prestressing forces cause a member to shorten or the strands are allowed to "relax", the tension stress in the strands decreases and the strands undergo a loss. A loss is considered to be a positive quantity. When loads cause the strands to elongate, the tension stress in the strand increases and the strands undergo a gain. A gain is considered to be a negative quantity. For typical construction, the losses will be greater than the gains, and the sum of losses and gains will result in an overall loss. Δf_{pT} will typically be a positive quantity that is subtracted from the jacking stress.

Section Properties

The AASHTO LRFD code allows the bridge designer to use either gross or transformed section properties when designing prestressed girders. Gross section properties are the properties of the girder section based only on the gross concrete area

without regard to the area of prestressing steel or other reinforcement. The advantages of gross section properties are that they are simple to compute and they do not vary along the girder length with the eccentricity of harped strands.

Transformed section properties are those properties that take into account the effective area of the prestressing steel as well as any other longitudinal reinforcement in the girder based on the steel-to-concrete modular ratio. The use of transformed section properties does have the advantage of implicitly accounting for all elastic losses or gains due to applied loads including prestress, dead load and live load. The use of transformed section properties is technically more correct and should yield a more accurate estimate of stresses in both the prestressing steel and the concrete.

When gross section properties are used to analyze prestressed girders the typical analysis assumes that the prestressing force in the girder remains constant during all loading conditions. However this is not actually true since the prestressing strands are bonded to the concrete and if plane sections remain plane the stress in the strands (and therefore the prestressing force) varies with girder loading. Gross section analysis does not account for this change in prestress force directly. Therefore, to account for this effect the prestressing force has to be adjusted by calculating the elastic losses or gains and subtracting or adding them to the initial force.

It should be noted that if transformed section properties are used for the structural analysis of the girder there is no need to consider elastic losses or gains in the prestressing strands, the change in the strand stress is already accounted for implicitly because of the adjusted section properties. This effect can be understood with the simple case of a 10" by 10" rectangular concrete section with 1.5 square inches of prestressing steel located at the center of the section with a steel-to-concrete modular ratio (Es/Ec) of 7.0. Assuming the force at transfer is 0.75*270 ksi the initial prestress force on the section is 0.75*270*1.5 = 303.75 kips. If transformed properties are used the section area becomes 10*10 + 1.5(7.0 – 1) = 109 sq. in., dividing the total initial force by this area results in a compressive stress over the total transformed area of 303.75/109 = 2.787 ksi. Since the transformed area of the steel is part of the total area that the force is applied to then subtracting this compressive stress times the modular ratio from the original tension stress in the steel gives the net stress in the steel, 0.75*270 – 2.787*7.0 = 182.99 ksi. Now if gross section properties had been used for the analysis then to find the effective stress in the steel the elastic losses must be calculated with Equation C5.9.5.2.3a-1, the result for this example is a loss of 19.24 ksi. The effective stress in the steel is then, 0.75*270 – 19.24 = 183.26 ksi. The effective stress from the gross section analysis is essentially the same, well within the level of accuracy of the design material properties.

ITD has historically used gross section properties for prestressed girder design, ignoring all gains in the prestressing force due to added dead load and live load. As a result we have a good history of crack free prestressed girder performance in Idaho. It is ITD policy to continue to use gross section properties ignoring added dead load and live load elastic gains.

Humidity

The average annual humidity in Idaho can vary from 70% in the far north to as low as 55% in the southwest part of the state. Since concrete shrinks more in a low humidity environment resulting in greater prestress loss it is conservative to assume a low humidity in designing prestressed girders, therefore it is ITD policy to use 55% humidity in design unless the designer has better information for a particular bridge location.

Revisions:

April 2008   Added new article.

Feb 2012   Deleted the approximate method of calculating losses by use of the table. The table has been deleted from the AASHTO LRFD Specifications.

Sept 2012   Corrected references to Method 3 to Method 2.